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Key factors of eddy current separation for recovering aluminum from crushed e-waste

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ABSTRACT

Recovery of e-waste in China had caused serious pollutions. Eddy current separation is an environment-friendly technology of separating nonferrous metallic particles from crushed e-waste. However, due to complex particle characters, separation efficiency of traditional eddy current separator was low. In production, controllable operation factors of eddy current separation are feeding speed, $(\omega R - v)$, and S_p. There is little special information about influencing mechanism and critical parameters of these factors in eddy current separation. This paper provided the special information of these key factors in eddy current separation of recovering aluminum particles from crushed waste refrigerator cabinets. Detachment angles increased as the increase of $(\omega R - v)$. Separation efficiency increased with the growing of detachment angles. Aluminum particles were completely separated from plastic particles in critical parameters of feeding speed 0.5 m/s and detachment angles greater than 6.61 deg. S_p/S_m of aluminum particles in crushed waste refrigerators ranged from 0.08 to 0.51. Separation efficiency increased as the increase of S_p/S_m. This enlightened us to develop new separator to separate smaller nonferrous metallic particles in e-waste recovery. High feeding speed destroyed separation efficiency. However, greater S_p of aluminum particles brought positive impact on separation efficiency. Greater S_p could increase critical feeding speed to offer greater throughput of eddy current separation. This paper will guide eddy current separation in production of recovering nonferrous metals from crushed e-waste.

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1. Introduction

Production of e-waste has been greater than 40,000 kt (Breivik et al., 2014; Robinson, 2009) in the world. Developing and undeveloped countries have been dumps of e-waste, not only self-produced but also imported from developed countries. High purity metals (gold, copper, aluminum, etc.) are contained in e-waste (Zhou and Xu, 2012). Meanwhile, hazardous materials (polyvinyl chloride, dechlorane plus, et al.) are also existed in e-waste (Stone, 2009; Ilgin and Gupta, 2010; Song and Li, 2014). If e-waste was not properly disposed, heavy metals and hazardous materials would expose to environment (Ruan et al., 2016; Xu et al., 2014). Therefore, recovering e-waste is a crucial work not only from resource and energy sustainable but also from environmental protection.

In past years, crude technologies (open incineration and acid washing) were employed to recover e-waste in China (Fig. 1). Heavy metals and hazardous materials accumulated in local soil, water, plants, and human bodies (Leung et al., 2008; Zheng et al., 2010). Recently, the technologies of recovering e-waste are developing. Green chemical leaching (Park and Fray, 2009), bioleaching (Ruan et al., 2014a), and physical separation (Yuan et al., 2012) were invented to dispose e-waste. Due to high-efficient and easily engineering, physical separation is the preferable method of recovering e-waste (Ruan and Xu, 2015).

Eddy current separation (ECS) is a physical technology of separating nonferrous metallic particles from other particles (Ruan and Xu, 2011a; Zhang et al., 2002). In ECS, alternating eddy current was induced in nonferrous metallic particles when meeting variable magnetic field generated by the rotation of magnetic drum of eddy current separator. The alternating eddy current caused a new magnetic field in nonferrous metallic particles. The magnetic field of eddy current separator and the new magnetic field had the same magnetic field direction. Thus, repulsive force between the two magnetic fields was generated and changed the movement of nonferrous metallic particles and separated them from other particles. No pollutions are generated in ECS. ECS was employed in mineral

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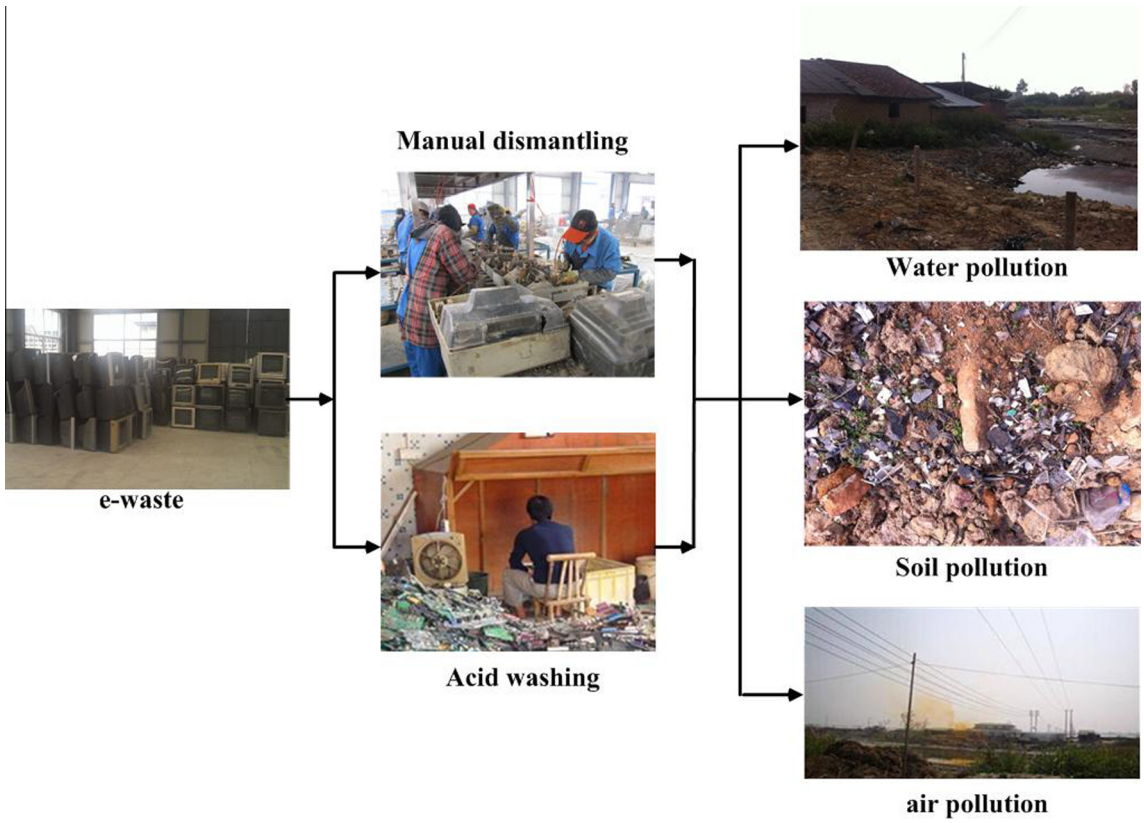

Fig. 1. Crude technologies of recovering e-waste and environmental pollution.

processing in past years (Lungu, 2005; Lungu and Schlett, 2001). It was also encouraged to recover nonferrous metallic particles from crushed e-waste (Ruan and Xu, 2011b; Ruan et al., 2010). However, nonferrous metallic particles in crushed e-waste were great differences in size, shape, purity from minerals. Therefore, traditional eddy current separator offered low separation efficiency of nonferrous metallic particles from crushed e-waste. The separation rate was less than 85%. For improving separation efficiency, models of ECS had been established to research the influencing factors (Maraspin et al., 2004; Ruan and Xu, 2012). However, parameters of separator structure and particle characteristics cannot be changed in production. Only S_p can be controlled by crusher screen. Thus, controllable factors of ECS are only feed speed, rotation speed of magnetic field, and S_p. These controllable factors are the key factors of ECS. How did these key factors influence the separation efficiency of ECS? There was little detailed information. This study provided detailed information about the influencing mechanism of these key factors and their critical parameters in ECS.

2. Materials and methods

2.1. aluminum particles and eddy current separator

Aluminum particles employed in this study were collected from crushed waste refrigerators cabinets. Waste refrigerator cabinets contained about 53.5 wt.% ferrous metals (iron, steel), nonferrous metals (6.3 wt.% aluminum and 2.6 wt.% copper), 22.5 wt.% plastics, 12.6 wt.% polyurethane (PUR) foam, and 2.5 wt.% trichloromonofluoromethane (CFC-11). An environment friendly production line for recovering waste refrigerator cabinets was proposed in our previous work (Ruan and Xu, 2011b). The line was consisted of closed crushing, activated carbon fiber absorption (ACFA), air current separation, magnetic separation, and ECS. These materials could be completely liberated when crushed into 5 cm. ACFA and air current separation were used to separate PUR foam and CFC-11 from crushed waste refrigerator cabinets. Magnetic separation was employed to separate ferrous metals (iron and steel). ECS was used to recover aluminum and copper particles from plastic particles of crushed waste refrigerator cabinets respectively. This study focused on ECS of aluminum particles from plastic particles of crushed waste refrigerator cabinets. The representative aluminum particles (T1, T2, T3, T4, T5, T6, R1, R2, R3, R4, R5, and R6) were presented in Fig. 2a. Physical characters of aluminum particles were given in Table 1. Triangle and rectangle were the classical shapes. Particles sizes ranged from 1.2 cm to 4.5 cm. According to Eqs. (2) and (3), form factors of triangle nonferrous metallic particles ranged from 0.339 to 0.375. Form factors of rectangle aluminum particles ranged from 0.143 to 0.235. Eddy current separator employed in this study was presented in Fig. S1. Diagrams of separation process were presented in Fig. 2b and c. Physical characters of separator were given in Table 2.

2.2. Models of ECS

The equation for computing magnetic flux density of magnetic field (B_r) was (Rem et al., 1997):

$$B_r = \sum_{n=1}^{\infty} b_n (r/R)^{-(2n+1)k-1} \sin(2n+1)k(\alpha - \omega_m t) \quad (1)$$

where b_n is Fourier coefficient, r is radius distance between the particle and the center of magnetic drum (m), R is radius of the magnetic drum (m), k is the number of pairs of the magnets placed in the magnetic drum, ω rotation speed of magnetic drum (rad/s), (α-$\omega_m t$) can be supposed as 90°. Models of ECS were established in previous work (Ruan and Xu, 2012; Ruan et al., 2014b). Models

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